5GECO: A Cross-domain Intelligent Neutral Host Architecture for 5G and Beyond

Joao Francisco Nunes Pinheiro*, Chia-Yu Chang‡, Tom Collins†, Eric Smekens†,
Revaz Berozashvili¶, Adnan Shahid§, Danny De Vleeschauwer‡, Paola Soto*,
Ingrid Moerman§, Johann Marquez-Barja*, Jens Buysse†, Miguel Camelo*

*University of Antwerp - imec, Internet & Data Lab (IDLab), Antwerpen, Belgium,
email: {joaofrancisco.nunespinheiro, paola.soto-arenas, miguel.camelo, johann.marquez-barja}@uantwerpen.be
†Citymesh, Oostkamp, Belgium, email: {tom.collins, eric.smekens, jens.buysse}@citymesh.com
‡Nokia Bell Labs, Antwerp, Belgium, email: {chia-yu.chang, danny.de_vleeschauwer}@nokia-bell-labs.com
§IDLab, Department of Information Technology, Ghent University, email: {adnan.shahid, ingrid.moerman}@ugent.be
¶Accelleran, Antwerp, Belgium, email: revaz.berozashvili@accelleran.com

***Abstract*—Radio Access Network (RAN) openness is a vision for 5G and beyond to avoid unnecessary vendor lock-in effects and introduce new business models. To expand the Open RAN (O-RAN) potentials, such as real-time control and data-driven intelligence, we propose a cross-domain 5GECO network architecture to let flourish the new Intelligent Neutral Host (INH) model in the value chain. Also, to realize this new model, we consider the role of a INH Service provider as having to define a Service Level Agreement (SLA) with its customers, called tenants, and a scheme to map said SLA into 5G technology (termed the 5GECO multiplet) is elaborated. It is noted that this 5GECO architecture considers sharing, control, and orchestration across both the RAN and the Transport Network (TN) domains. Finally, three key challenges are identified for an INH Service Provider, along with a preliminary solution analysis, ranging from Radio Resource Management (RRM) optimization, cross-domain low-latency, and flexible virtualized resource scalability.**

***Index Terms*—5G, Neutral Host, MOCN, Machine Learning, RAN, Transport Networks, Network Slice, Artificial Intelligence**

I. Introduction

The introduction of 5G improves the user experience and opens up new options to restructure mobile networks and disrupts existing business models. Some crucial characteristics, in particular flexibility, openness, and intelligence, are projected to evolve the RAN. Therefore, standardization development organizations and industry fora, such as O-RAN Alliance[1] and Telecom Infra Project[2], concretize these visions into requirements and standardize open network interfaces among disaggregated RAN entities, e.g., Distributed Unit (DU) and Centralized Unit (CU), with the software-defined RAN capability through the Near-Real-Time RIC (NearRT-RIC) and Non-Real-Time RIC (NonRT-RIC). In this regard, "*Open RAN*" is feasible by suitable programmability and extensibility, and legacy monolithic RAN is turned into an ecosystem of multi-vendor, inter-operable, and autonomous RAN, with the benefit of reduced cost, improved performance, and agile control.

However, the aforementioned network technology evolutions must be exploited to expand current business models, like Neutral Host (NH), throughout the value chain or even build new portfolios. Moreover, this updated model must come with new SLAs between INH Service Providers (which we will refer to as **INH** for simplicity) and its tenants, as well as particular schemes to characterize the mapping to 5G technology. Furthermore, to assist the deployment blueprint for this new model, the related network architecture will be re-sketched to include all of its relevant network domains and Network Functions (NFs). Finally, a highlight of the challenges for continuous operation and optimization shall be provided.

Following this narrative, we first provide background knowledge of the trend from passive/active RAN sharing to perform RAN "slicing"[3] in conjunction with the NH model in Section II. Section III gives a detailed explanation of the proposed INH model, the updated roles in the value chain, and the two key aspects to be revisited, i.e., SLA between INH and tenants and the 5GECO multiplet. Our proposed 5GECO architecture is finally shown in Section IV which spans both the RAN and the TN domains to tackle the issues of sharing, control, and orchestration in these two domains. Finally, in Section V, three key challenges for continuous operation and optimization of an INH are introduced, and the respective preliminary solution analyses are depicted.

II. Background knowledge

To realize the goal of an INH, two well-known background knowledge are exploited: (1) RAN sharing and RAN "slicing", and (2) Neutral host. In the following, we present a comprehensive overview of both.

A. RAN Sharing and RAN "Slicing"

Mobile network sharing has been investigated since 3G to balance network investment and time-to-market for the new mobile communications generations while still mandating regulatory requirements [1], [2]. Unlike the traditional Mobile Network Operator (MNO) business model, which is based on the full ownership of network infrastructure by the carrier, the sharing concept leads to a multi-operator landscape with the redistribution of assets and operational responsibilities.

[1] https://www.o-ran.org/ [2] https://telecominfraproject.com/

[3] The research to slice the RAN is still ongoing, while 3GPP only standardizes "RAN support for Core Network Slice Selection".

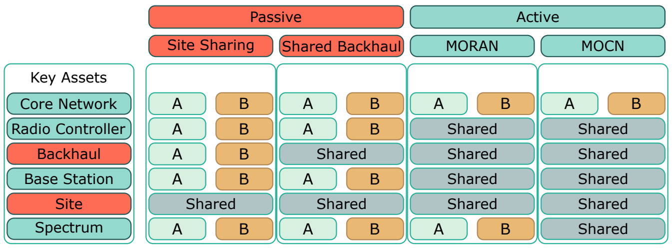

Fig. 1. Passive and active RAN sharing, including MOCN and MORAN.

As a result, specialized operators can focus on activities that differentiate them from the others (e.g., verticals tailored Quality-of-service (QoS) policies, intent-driven autonomous network operation, or application-aware networking), not just providing coverage and capacity [3].

RAN sharing, in practice, aims to share passive/active access network equipment (e.g., cell sites, antennas, towers, power, masts, xhauls, etc.) among multiple operators [4]. An example of passive RAN sharing is to share both the site and the tower to save on expenses for site acquisition, infrastructure, lease, and maintenance, as well as to improve sustainability by lowering network footprint. Backhaul sharing [5] can further be introduced to reduce the cost of equipment (e.g., fiber) and deployment (e.g., joint trench digging).

Specifically, two active RAN sharing models are most common: Multi-Operator RAN (MORAN) and Multi-Operator Core Network (MOCN), as shown in Figure 1. In specific, MORAN [6] solution allows operators to maintain the highest degree of independent control over their cell-level parameters and individual spectrum, while site-level parameters are shared. MOCN [7], on the other hand, is a 3GPP-standardized approach to further sharing the used spectrum. By doing so, not only can extra savings be made by reducing operating and planning costs, but spectrum pooling can boost efficiency. Nonetheless, MOCN comes at the expense of increased complexity in the Radio resources sharing process[4].

With the introduction of 5G, the concept of RAN "slicing", which must be understood as "RAN support of core network slicing" as it now appears in 3GPP Rel 17, is established over RAN entities to create a variety of network services [8]. Unlike core network slicing, RAN "slicing" has its own particular challenges set in terms of radio resource abstraction, allocation, and isolation among numerous slices [9], not to mention the added complexity introduced by 5G like different numerologies and RAN disaggregation [10]. Further, with the goal of open interfaces and real-time intelligence, a new paradigm from the O-RAN model, with programmable optimization using RAN Intelligent Controllers (RICs) [11] is shown through service model abstraction and data-driven closed-loop control.

B. Neutral Host

The concept of NH stems primarily from the use of small cells, that is, the Small Cells as a Service (SCaaS) model [12], to deploy and manage several small cells that can be utilized by multiple MNOs to offer services to their customers [13]. This is due to generally the relative higher cost per Mbps per Small cell deployment. Therefore, the capacity delivered by the SCaaS provider (also called "INH Service provider" in this paper) can supplement existing networks to increase capacity in some hot spots and improve in-building coverage. In this way, the multi-tenancy concept allows the provisioned small cells to be shared between multiple operators, denoted as tenants.

In addition to the above SCaaS operation model, a spectrum-based NH is also present [14]. In this case, the NH provider is a fully-fledged MNO; that is, it has the full right and its own radio resources that also host other different MNOs as roaming or tenant partners using the Licensed Shared Access (LSA) model for spectrum sharing. Also, the spectrum can be made up from shared access spectrum, for example, the Citizen Broadband Radio Service (CBRS) in the US, via tiered spectrum access models and a management entity to offer substantial amounts of spectrum [15].

NH excellently matches the 5G vision, thanks to the technology adoption of Network Function Virtualization (NFV), multi-access edge computing, Service-Based Architecture (SBA), and multi-service deployment via network slicing [16], [17]. From this perspective, the NH provides each operator with a virtualized RAN spanning the covered area to serve their corresponding end users.

Furthermore, there exist several techno-economic analyses of NH [18]. One NH operator model analysis by the Lux-Turrim5G initiative is provided in [19] to drive a business environment to install 5G microcells on light poles all over the city. Further, it is shown that the NH business can be expanded from densely populated urban regions to some specialized venues [20], [21] or rural areas [22] to increase not only connectivity but also benefit all stakeholders. An analysis of the existing NH businesses [23] reveals that the markets nowadays are highly diversified.

III. Intelligent Neutral Host and its Enablers

Based on the above background overview, we can see that the technology evolution is tightly coupled with the new business models. In this section, we first define the INH, address the updated roles in the value chain, and inspect two key aspects: (1) SLA between INH and its tenants, and (2) 5GECO multiplet.

A. Intelligent Neutral Host

As outlined in Section II-B, INH is the entity that provides network infrastructure to multiple network service providers. By embracing the O-RAN paradigm, NH can flexibly compose the network using multi-vendor network functions with an open interface and enable near- or non-real-time control loops for its tenants using the NearRT-RIC, which is tailored for operations in the millisecond scale, or NonRT-RIC, which is used for operations in the scale of seconds to minutes, respectively. Further, given new xHaul segments in the 5G RAN across disaggregated RAN entities (i.e., front-, mid- and backhaul), the NH shall also apply the Software Defined

[4] Core Network (CN) sharing is also feasible, in which all key assets are shared, but it limits possibilities to differentiate services for operators.

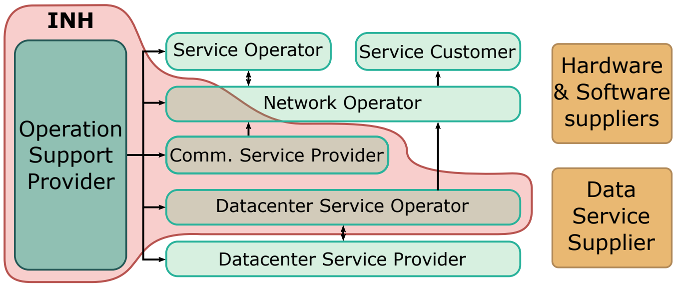

Fig. 2. Updated roles in value chain.

Networking (SDN) capability to control potential network congestion in the TN shared by its tenants, particularly on the shared midhaul and/or backhaul segments.

Based on the aforementioned observations, we expect that a legacy NH will evolve into the INH via two further extensions. First, the tenant can take advantage of the optimization algorithms executed in the RICs that will be developed, implemented and deployed by the INH provider, sharing the capacity offered by the modulation of its own spectrum bands. Such algorithms will be driven by the collected data as inputs to the Machine Learning (ML) model to optimize the shared radio resources dynamically, Physical Resource Blocks (PRBs) for example, and to provide tenants and their subscribers with specific QoS or 5G QoS Indicator (5QI) parameters according to their defined SLAs.

As the second extension, the INH will further include the TN domain via controlling the shared xHaul segments. Such an extension is not surprising, since the end user experience (e.g., low latency) shall be considered from an End-to-End (E2E) perspective, whereas the TN may be a bottleneck due to the sharing for various tenants and multiple xHauling (e.g., mixed backhaul and midhaul traffic on the same link). It is worth noting that the control and optimization of shared TN shall be based on the relevant SDN controller, which must communicate with the RIC belonging to the same INH. The objective for this is to employ unique traffic identifiers and preserve per-bearer QoS.

B. Actors and Roles in Value Chain

On top of the above INH definition, we can see that an INH shall coordinate multiple network domains and perform optimization. This does not only include key parameter tweaks but also the management, orchestration, and placement of different network functions to fulfill the tenant's SLAs. Therefore, given this new INH vision, an update on all roles in the value chain is shown in Figure 2 with the following details:

- **Service Operator** is a communication application provider that provides telephony, data, and other communications services. For example, in Belgium, the Astrid[5] network provides voice services to Public Protection and Disaster Relief (PPDR), and added data communications for its users.
- **Service Customer** uses services offered by a network operator. In 5G era, vertical industries are considered as the major actors in this role, e.g., a smart stadium , to support extra services to its users, e.g., smart navigation and multiple game viewpoint.
- **Network Operator** is in charge of orchestrating resources (i.e., chunk, slices), potentially for multiple tenants. Based on the INH vision, this role will use aggregated infrastructure services to design, build, and operate network services offered to both Service Operators and/or Service Customers.
- **Communication Service Provider** comprises the role of a traditional telecommunications service provider, who owns the infrastructures as well as provides the necessary communication services needed by the network operator. In the context of a cross-domain INH, this role will further be responsible for TN infrastructures.
- **Data Center Service Operator** offers data center services and designs, builds, and operates its data centers. The network operator will utilize these services to improve its business output and profitability.
- **Operation Support Provider** comprise systems used by the above-mentioned service providers to manage the networks. They support management functions such as network inventory, service provisioning, configuration, and fault management. Together with business support systems, they deliver various E2E network services.
- **Hardware and Software Suppliers** are the manufacturers and the solution integrators which offer the required hardware infrastructure and software components over the complete stack.
- **Data Service Supplier** provides the supplemental software required by the communication service provider and network operator.
- **Datacenter Service Supplier** enables data access on demand to the data center service operator.

C. Service Level Agreement between INH Service Provider and its Tenants

The analysis of 5G SLA is emerging to roll out advanced technology for new services. In [24], six types of SLAs are outlined, of which two are related to the INH: Post-established flexibility and Emerging types. The former determines whether a SLA will be continuously evaluated at run time and adjust the requirements and metrics in real-time, whereas the latter specifies whether the SLA for a slice is shared among a specific number of customers or follows a designed order to serve its customers.

However, which metrics are of interest for SLA require a thorough study of the use case, as each has its own QoS mechanisms and architecture, which must be identified by a set of Key Performance Indicator (KPI) requirements [25]. Given the complexity and variety of the use cases, continuous testing and SLA management for the network are expected on a per-UE (user equipment) and per-SLA basis [26]. Note that the INH's goal is to provide tenants with SLAs that go beyond best effort (although public networks may still be offered at best effort), taking into account dense environments and private use-cases. This will go beyond 3GPP specifications, delivering not only best effort, mission-critical (guaranteed video) and

[5] https://www.astrid.be

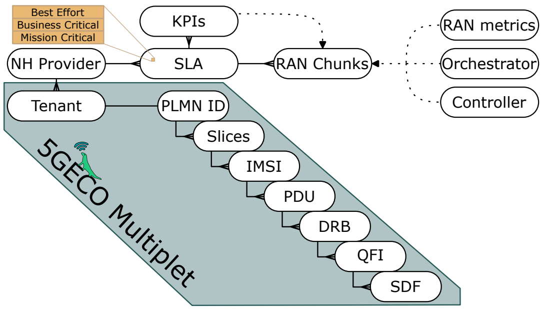

Fig. 3. 5GECO Multiplet scheme.

delay-critical (time-sensitive industrial automation) [27], but also custom levels of 5QIs for QoS.

In this sense, for each INH tenant, the SLA will be defined based on factors such as business model, SLA structure, QoS specifications, cost model, and level of service between slices that is requested. Specifically, it is described by the allocation of Resource Blocks (RBs), which the tenant will be able to allocate between their network slicing and 5QI functions to guarantee their own subscribers. It should be noted that the requirements of the tenant (e.g., data sharing) and limited functionality imposed on 5QI functions and network slicing are necessary to manage overall INH optimizations.

D. 5GECO Multiplet

Based on the above analysis of SLAs between the INH and its tenants, we further develop a scheme to characterize the mapping to 5G connectivity and enable a deployment blueprint. Such a scheme is termed *5GECO Multiplet*, as depicted in Figure 3, in which several parent-child and one-to-many relationships are shown to illustrate the hierarchical connectivity model that the INH must monitor to dynamically allocate radio resources to each of its tenants, thus satisfying the agreed SLA. We can also see that an INH provider is responsible for guaranteeing SLAs across all tenants by various suitable KPIs within the defined SLA (that should go beyond best effort). These KPIs will be used to dictate capabilities within the radio resource budget (called RAN chunks) allocated by the INH to each tenant, which must be further controlled, orchestrated, and monitored in real-time in order to respect the SLA agreed between INH and each Tenant.

Moreover, this 5GECO multiplet is to be considered by the INH for each of its tenant, starts from the tenant's Public Land Mobile Network (PLMN) ID broadcasted by the INH radios, and it goes down via the tenant's core network slices, to reach all tenant's subscribers' International Mobile Subscriber Identities (IMSIs) accessing the INH radio. Then, by taking additional hierarchical steps down, each subscriber traffic is composed of the respective Protocol Data Unit (PDU) sessions, Data Radio Bearers (DRBs), QoS flows, and finally, to Service Data Flows (SDFs).

We can see that the 5GECO multiplet results in a tree-like data structure in which the monitoring information is aggregated and exposed to the corresponding xApps and rApp on top of NearRT-RIC and NonRT-RIC to ensure SLA. To conclude, Table I summarizes all data property sources, categorizes them into three distinct monitoring levels, and identifies the interface characteristic that can be applied as well as the prerequisite information needed from the tenant's core, e.g., shared Single Network Slice Selection Assistance Information (S-NSSAI) information.

IV. 5GECO Architecture

To realize the INH vision, the 5GECO architecture is proposed in Figure 4. Such an architecture spans the disaggregated RAN entities and includes the shared xHaul TN, i.e., midhaul and backhaul. This is due to the fact that the cost of 5G xHaul transport is a major concern for INH to realize dense business cases (e.g., smart stadium), and the Passive Optical Network (PON) is an economically efficient technology for xHaul transportation to support numerous cells within a small geographic area, not to mention the ability to leverage existing Fiber To The Home (FTTH) for additional benefits. Further, an east-west Application Programming Interface (API) is sketched between the corresponding controllers of RAN and TN, i.e., NearRT-RIC and SDN, to align and synergize the control and operation processes as well as to achieve collaboration, communication, and optimization.

In addition, to realize the continuous testing and SLA management purposes for each INH tenant, the NonRT-RIC and SDN management sit on top using the north-south API for E2E management and orchestration. For instance, the INH will provide a SLA decomposition unit that breaks down a top-level SLA into domain-specific ones specialized for RAN, TN, and even core domains. It is worth noting that such breakdown methodology initially assumes statistically independent domains [28]; however, further investigation is needed on the correlation in between domain SLAs. Each SLA will contain the relevant KPIs of each domain that can be enforced as policy and monitored as metrics to ensure SLA, e.g., particular QoS and 5QI parameters. Also, there are at least two constraints must be considered when allocating PRBs: First, according to INH policy, the total number of PRBs allocated from a specific category (shared, prioritized, and dedicated - as per 3GPP TS 28.541) is limited; Second, a minimum number of PRBs shall be allocated to each tenant, particularly to each tenant, the Slice level.

To take one more step, such architecture can apply the Artificial Intelligence (AI)/ML framework defined by O-RAN alliance [29] to realize the AI/ML lifecycle framework by utilizing collected data from RAN and TN, and taking into account the routes taken for each traffic flow (e.g., core data center or edge breakthrough). In particular, the INH can train a variety of AI algorithms controlling RB allocation and route selection for each tenant and then compare them using diverse validation datasets to identify their effectiveness (or point out that they are all under-performing) in fulfilling SLAs. Finally, the selected algorithm will be deployed and executed at the inference host (e.g., NearRT-RIC) for continuous operations.

V. Optimization Challenges for INH

Based on the above architecture design, three key challenges are seen to optimize the RAN radio resource, cross-domain in-

TABLE I

5GECO Multiplet active monitoring levels

Active Monitoring Level	Data property source	Interface Characteristics	Pre-requisites information from tenant's core
Level 1 - Subscriber usage	SDF, QFI, DRB, PDU	Near Real-time	Shared S-NSSAI and Subscriber counters according to SLA
Level 2 - Slice usage	Number of Slices, Slice allocation, IMSI allocations	Near Real-time	Shared S-NSSAI
Level 3 - Chunk usage	Chunks usage and assignment	Non Real-time	-

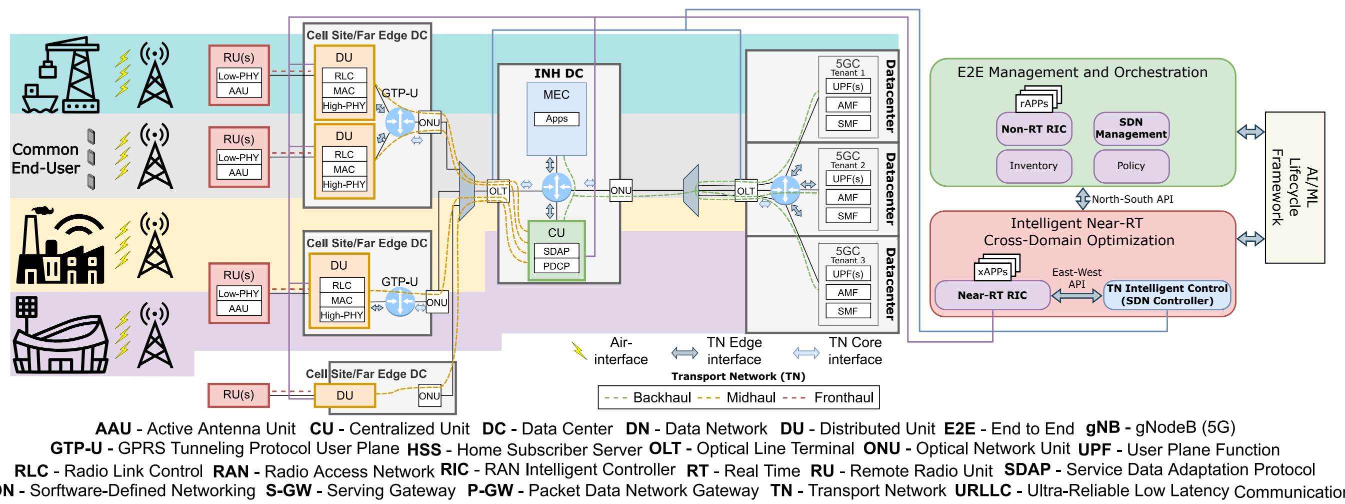

Fig. 4. 5GECO End-to-End Network Architecture.

teractivity for low latency, and virtualized computing resource scaling for Management and Orchestration (MANO) system.

A. Radio Resource Management Optimization

To support the RAN chunk allocation by INH to each tenant, one key optimization problem is to maximize the overall INH utility function, which is made up of individual KPIs defined through per-tenant SLAs. In practice, a tenant-specific function will map all KPIs to a value that quantifies its satisfaction, according to its SLA. In addition, there are two types of constraints that must be considered when allocating PRBs. First, according to INH policy, the total number of PRB allocated from a specific category (shared, prioritized, and dedicated) is limited. Second, a minimum number of PRBs shall be allocated to each tenant, particularly to each tenant, Slice level[6].

B. Cross-domain Low-latency User Interactivity

Low-latency feature is crucial for users migrating to 5G, and 3GPP put a lot of effort into reducing 5G New Radio (NR) latency in light traffic scenarios to as low as 1 ms by adopting certain configurations. However, each user neither has a dedicated base station, nor always uses the network during light loaded hours (e.g., midnight to early morning). In this regard, this low-latency feature by 3GPP will not appear in everyone's everyday life. In contrast, if the user traffic is unaware of congestion events in the network, it will build up queues in the network, causing even an ultra-fast connection to experience considerable delays.

In this regard, Low-Latency Low-Loss Scalable throughput (L4S) technology [30] is introduced to reduce queuing delay and improve latency by employing scalable congestion control along with active queue management by packet marking. To reach this goal, a list of requirements - known as the "Prague requirements" [31] - were set to properly improve on existing congestion control and avoid network pitfalls. To apply L4S in the cross-domain 5GECO architecture, the packet marking mechanism shall be introduced at the places where the network congestion mostly happens, i.e., DU and shared xHaul, and the data rate, packet marking probability, and queuing delay are monitored to ensure SLA fulfillment.

C. Flexible Virtualized Computing Resource Scaling

Virtualization technology allows RAN disaggregation; however, resource scaling of each virtualized RAN nodes (e.g., CU) is key to avoiding performance degradation, particularly when dealing with fluctuating user traffic that depends on multiple factors such as time, location, distance to the base station, etc. In this context, scaling algorithms are used for MANO operation to follow the traffic demands so each virtualized component that is affected by user traffic can be scaled and resolve conflicts, if the total amount of resources is not sufficient.

The scaling problem can be viewed as a decision-making problem, as it determines the number of resources allocated to achieve SLAs among tenants, it can be modeled as a Markov

[6] Such constraint can be replaced or even removed based on different roles in the value chain, e.g., PPDR service or best effort SLAs.

Decision Process (MDP) [32]. The Reinforcement Learning (RL) algorithm can been used to solve MDPs, and the optimal policy will be found after many agent interactions with the environment. As the first stage to tackle this problem, our focus is on the vertical scaling (i.e., the number of resources allocated to each Virtual NF (VNF) is increased or decreased). Further re-evaluation on horizontal scaling, i.e., increase the number of VNFs, will be conducted to improve the solution.

VI. Conclusions and Future Work

In this paper, we introduced the new INH model and the corresponding 5GECO network architecture to realize sharing, control, and orchestration across both RAN and TN domains. Additionally, a revision to the SLA definition between INH and its tenants, and the new 5GECO multiplet scheme to map into 5G technology were elaborated. Finally, three distinct challenges for an INH are given, along with some insights on the solutions.

Future works include development and deployment of the presented architecture in an experimental environment. In regards to the optimization problems, quantitative and qualitative evaluations of different algorithms are foreseen in order to achieve continuous operation and optimization for an INH.

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